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## Editorial

# CUREs in Biochemistry—Where We Are and Where We Should Go

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## Abstract

Integration of research experience into classroom is an important and vital experience for all undergraduates. These course-based undergraduate research experiences (CUREs) have grown from independent instructor lead projects to large consortium driven experiences. The impact and importance of CUREs on students at all levels in biochemistry was the focus of a National Science Foundation

funded think tank. The state of biochemistry CUREs and suggestions for moving biochemistry forward as well as a practical guide (supplementary material) are reported here. © 2016 The Authors Biochemistry and Molecular Biology Education published by Wiley Periodicals, Inc. on behalf of International Union of Biochemistry and Molecular Biology, 45(1):7–12, 2017.

**Keywords:** *course-based undergraduate research; pedagogy; CURE*

## Overview

Vision and Change calls upon science educators to train the next generation of scientists to be literate in overarching core concepts and understand the process and the interdisciplinary nature of science [1]. It is a call to action to inte-

grate student-centered learning to create student communicators and collaborators, while growing students' quantitative competencies and basic abilities to interpret their world through the lens of data. One of the key components of the report is for all biology learners to engage in research. The 2012 President's Council of Advisors on Science and Technology (PCAST) recommended both the adoption of validated teaching techniques and the creation of research experiences for first and second year STEM students [2].

Through an NSF Research Coordination Network—Undergraduate Biology Education grant, “Promoting concept driven teaching strategies in biochemistry and molecular biology through concept assessments,” biochemistry and molecular biology educators came together to discuss and define their field's “Vision and Change.” Over the past 6 years faculty from 475 institutions defined and refined foundational concepts and theories [3], the necessary

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technical skill set [4], and essential concepts and theories from allied STEM fields [5] at workshops across the country. Obstacles to adopting and implementing the envisioned curricular changes based upon individuals' institutions and resources became apparent through these workshops. To address this emerging need and develop strategies to overcome these perceived obstacles, grant leaders brought together small groups of experts and community stakeholders to discuss targeted topics through think tank meetings. This editorial describes the meeting held on course-based undergraduate research experiences, or CUREs, and offers a guide on CURE implementation as a community resource.

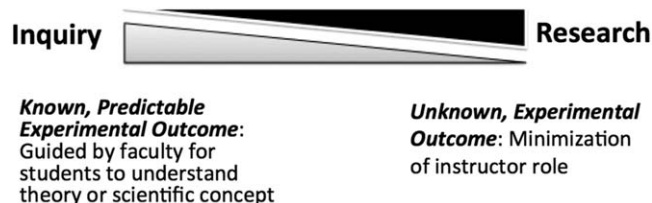
## Why CUREs

Part of reenvisioning biochemistry and molecular biology curricula in the footsteps of Vision and Change and the PCAST report includes incorporating high-impact practices (such as research experiences [6]) as an integral component of students' STEM education. Using a variety of assessment approaches including student self-reported gains, pedagogical research suggests that research experiences influence students' persistence in science and have positive outcomes in conceptual understanding and skills development [7–16]. However, implementing an authentic research experience for all students was identified as an obstacle to curricula reform. A spectrum of models to provide research apprentice-like opportunities was outlined by Wei and Woodin (2011) for biological life sciences, each with their individual strengths [17]. While there are many ways to provide a more research-based laboratory education, a traditional apprentice model provides a strong approach to support student scientists-in-training and remains the paradigm [18, 19].

Unfortunately, the sheer number of biochemistry and molecular biology students relative to the number of faculty mentors at large and small institutions precludes an apprenticeship model approach from meeting all student demands. Logically, focus has turned to embedding research into the curriculum, where more students could be engaged simultaneously. Course-based undergraduate research experiences (CUREs), like the HHMI-funded SEAPHAGES [20] program and the Genomic Education Partnership (GEP) [21], have proved to be successful platforms to deliver cooperative, inclusive, and sustainable molecular biology research experiences.

Integration of active scientific learning in the classroom are highly developed and the effect well evaluated; however, there are no current study of the impact of these pedagogical approaches vs. CUREs. Unlike traditional teaching laboratories CUREs provide this research experience to a wide audience. There are a number of ways students are able to gain research-like experiences ranging from guided inquiry to research. CUREs are distinct experiences from these classroom models (Fig. 1). In inquiry research,

## Inquiry vs. Research Based Learning



**FIG 1** The spectrum of non-traditional teaching approaches.

instructors guide students to a known answer. In contrast, a CURE does not have a defined outcome or answer. Instead, students may ask scientifically relevant and unpublished questions and develop experiments to test these hypotheses or be guided to tackle questions posed by the instructor as may take place in graduate research laboratories. For institutions and faculty, the question is then how can we develop, implement, sustain, and propagate CUREs?

## Best Practices and Supporting Evidence for CUREs

Research experiences improve persistence as measured by graduation and retention rates in STEM majors. When compared to traditional and inquiry-based approaches, does a CURE meet or exceed their effectiveness and why? The answers to this question are not all known, but a framework has been built on which we can now test components of CUREs to determine their contribution to positive student outcomes. At the project level, all pedagogical approaches can be separated into three design principles: discovery (generation of unknown questions to create new knowledge), iteration (building upon known findings to advance a scientific question), and student ownership (separating traditional and guided inquiry approaches from research models, both apprentice and CUREs). Each of these aspects are integrated into the elements of a CURE as described as we define the distinct features of CUREs. These project-level design principles must contribute to scientific identity, science self-efficacy, and values alignment at the student level to attain the positive student outcomes noted.

## The Think Tank

The think tank group, comprised of experts in CUREs and their implementation and stakeholders from community colleges, primarily undergraduate universities, and R1 institutions, assembled in November 2015 to:

1. Summarize the current state and potential for use of CUREs in higher education.

2. Identify faculty and institutional barriers to CURE adoption.
3. Provide best practices and supporting evidence for CUREs.
4. Discuss institutionalizing CUREs at community colleges and four-year institutions.
5. Create a booklet to guide those interested in creating sustainable and collaborative CUREs for biochemistry and molecular biology (see additional resources on the BAMBED webpage).

In this editorial, we summarize the meeting discussion and offer a guide on CURE implementation as a community resource.

## Select CURE Examples

### Institutional CUREs

University of Maryland-College Park's First Year Innovation & Research Experience (FIRE) program, based on the University of Texas's Freshman Research Initiative (FRI), engages first-year students in research through three core features: broad mentorship (personal, academic, research, and professional), faculty-led research, and general education degree credit. The three-semester program includes coursework to train students in research analysis methods, collaborative proposal development, and scholarly communication. In the second and third semesters, students conduct research within a faculty-led research team. Implementing a first-year CURE allowed UMD to engage a diverse population of students with the goals of increasing scientific literacy, capacity and self-efficacy.

### Integrating Synthetic Biology into CUREs

Synthetic biology uses engineering principles and mathematical modeling applied for the design and construction of biological parts, devices, and systems for end uses in energy, medicine, and technology. Using a collection of characterized DNA parts such as promoters, ribosome binding sites, coding sequences, and terminators, synthetic biologists use standardized assembly methods such as BioBrick assembly and Golden Gate Assembly to build genetic circuits in prokaryotic and eukaryotic cells. This approach is accessible to students at all education levels. The pClone system provides an entry point for synthetic biology promoter research [22] and allows students to have a research experience in the context of a laboratory course. It is also an inexpensive and easy prep, requires minimal training for faculty, can be implemented at diverse institutions, and scales easily with a mechanism to disseminate research findings (i.e. GCAT Registry of Functional Promoters). Moreover, to increase the accessibility, developers have made pClone available through Carolina Biological Supply Company. The pClone system serves as an example of the minimization of barriers to CUREs implementation.

## Definition of, and Assessment Strategies for, CUREs

Research experiences have a major effect on persistence in science and positive outcomes in conceptual understanding and skills development. There are several critical aspects of a CURE (i.e. ownership, iteration, discovery, etc.) that are hypothesized to contribute to these outcomes [23, 24]. These studies highlight the several studies of CUREs as well as highlighting assessment that still needs to be conducted. Influenced by this work, the following five elements have been proposed as defining features of CUREs, which may also make them distinct from traditional lab courses:

1. Use of scientific practices (asking questions, building hypothesis, designing studies and communicating);
2. Discovery of unknown questions, differing from inquiry where the instructor knows the answer, but not the student;
3. Broadly relevant work that is important to a community and could potentially become a research publication or other scholarly contributions including annotated database entries;
4. Collaboration. Science is not conducted in a vacuum and requires collaborations. CURE students should work collaboratively to reflect the best practices of scientific research;
5. Iterative processes to build upon or confirm earlier work and advance questions.

While the impact of some CURE components has been examined [25, 26], several interesting aspects of CUREs remain to be carefully analyzed [23].

### CUREs at Community Colleges

Since half of all college students enroll at a community college, it is critical to include these institutions in efforts to broaden student access to research experiences. Like CUREs at four-year institutions, CUREs at community colleges can be built around faculty research interests as well as collaborations with other institutions or local industries to provide this experience for a very diverse student population. CUREs that involve collaborations with transfer institutions have the added benefit of providing valuable bridge experiences for students. CUREs in certificate and technical programs provide students with relevant and marketable skills as well as potential employment opportunities with local businesses and industries. Community colleges have developed a network of active participants in research, primarily in biology, through the Community College Undergraduate Research initiative (CCURI.org). CCURI provides opportunities and funding for professional development and collaboration among faculty. Community colleges are also increasingly involved in one-on-one structured partnerships with Bachelor degree-granting institutions, which may provide natural venues for CURE



collaborations. An example is the Howard Hughes Medical Institute funded project that included partnering a four-year liberal arts university, Hamline University with two community colleges, Century Community College and North Hennepin Community College to develop the “Engaging Science Students through Investigative Research.”

## What is Missing? Sciences in the Humanities

While early research experiences increase the retention and motivation of STEM students, these practices are not regularly extended to non-science major students. Vision and Change emphasized the need for all students to understand the scientific process, including future politicians, business leaders and community leaders. If the impacts of CUREs are critical for a positive outcome of STEM students, why would this not also be a critical and influential experience for all students? Nonscience majors often have negative attitudes towards science [27], while CUREs have been suggested to have a positive impact on understanding of the process and nature of science [28]. The use of CUREs in science courses for nonscience majors and liberal arts courses could have significant impact on all students understanding of, and attitudes toward, science.

## Faculty and Institutional Barriers to CUREs Adoption

Change often meets resistance. We defined four major classes of barriers to faculty implementing CUREs: student, institutional, fiscal, and temporal.

### Student

Anxiety pertaining to poor student evaluations, student resistance to a new pedagogy, and heterogeneity of student preparation and faculty perception of student reactions were identified. Clear and repeated communication to students on the potential benefits they can receive from the CUREs approach and ensuring transparency in implementation were identified as means to address this barrier.

### Institutional

Barriers included institutional culture and tradition and maintaining accreditation or transfer-articulation agreements. Faculty-erected barriers arose from maintaining consensus for shared instruction, meeting the needs of subsequent courses, and assessing impact to show efficacy, especially at the community college level. Additionally, faculty concerns over institutional “buy-in” were discussed. To address these institutional/faculty barriers, use of innovative pedagogy like CUREs should be linked to promotion and tenure consideration. We also discussed the possibility that CURE education could represent a stark advantage to traditional university settings in the face of online and

remote college educational options. Furthermore, the development of assessment tools to support incentivization of CURE implementation by deans/department chairs and the creation of mentoring networks and institutional partnerships to raise the profile of adoption and acceptance of new pedagogy would be beneficial in overcoming these barriers.

### Fiscal

Lack of transparency in funding for teaching stymies change. Faculty must plan for adequate research supplies, identify space/facilities to accommodate research-based experiments and schedules, and train staff and faculty to support curricular changes. To address fiscal concerns, the group discussed using partnerships to share material costs, tying investment in the course to the institutional mission to garner administrative support, and repurposing space through documenting needs. Development of video-based training for lab implementation, mapping out publications based upon student results, grant proposal writing to sustain CUREs, and the aforementioned “how-to” manual could provide low-cost mechanisms for training staff and faculty.

### Temporal

With a limited amount of time to develop and implement changes to the curriculum, faculty would be more likely to adopt readily available model systems to “plug” into their CURE. While the impact of the consortium CUREs (GEP and SEA-PHAGE, for example) are impressive and well recorded, no such large-scale protein-based consortium exists. In BAMBED and other educational journals, examples of single investigator/institution integration of research into the classroom exist, but these examples function in isolation, lacking the collaboration that promotes long-term authentic research evolution and team-based skills. Again, partnerships between institutions can begin to develop these resources, but an organized community effort would be better positioned to provide the variety and depth of projects necessary to sustain CUREs in the biochemical curriculum.

## Institutionalizing CUREs at Community Colleges and Four-Year Institutions

What are the institutional goals of implementing a CURE? Some examples may include: increasing graduation rates, reducing years to graduation, improving discipline-specific retention, broadening inclusion of students to build a more diverse scientific community, building institutional, departmental or program reputation, providing a track for students, answering the value of higher education (value proposition), or increasing research productivity. Once the institution’s goals are defined, the roadmap to institutionalizing a CURE could be as follows:



1. Develop a pilot program.
  - a. Implement CUREs in a low risk/high payoff targeted course with a select group of stakeholder.
  - b. Define learning objectives and outcomes to demonstrate efficacy.
2. Build consensus through broadly engaging stakeholders (students, faculty and staff).
3. Identify funding to support scaling up.
4. Build a community of expertise in practice.
5. Recruit faculty participants through call for proposals that define criteria of participation consistent with institutional goals.
6. Develop cohorts of faculty to sustain practice.
7. Develop an iterative process of sustaining, assessing, and modifying to meet goal(s).

## Conclusions and Open Invitation

Biochemistry students benefit from research experiences, however the opportunity is limited due to student demand. Access to research internships often occurs late in a student's college experience, reducing the impact on a student's educational trajectory. We identified key components of CUREs and CURE implementation with the intention of bringing them to the attention of the biochemistry community. While critical assessment of the CURE pedagogy has been and is being completed [23, 26], several aspects of CUREs still need to be evaluated. Furthermore, it is clear that several areas of biochemistry, including protein biochemistry (ranging from enzyme kinetics to structure and function as well as industrial and medical use of proteins), are not well represented by current CUREs. While there are many good individual instructors or institutions conducting protein/biochemistry based CUREs (a list of examples published by BAMBED are provided in the booklet), there are no large biochemistry-centered consortiums that provide critical elements as observed with GEP and SEAPHAGE. As a result, the gains made in some disciplines have not reached the same level in protein chemistry and other areas of biochemistry. We present suggestions to address some barriers to adoption, and endorse the creation of a clear and easily definable resource to define, create, and assess CUREs in our field. Finally, with the many student and faculty gains in learning and engagement by CUREs, we believe that it is crucial for the biochemistry community to participate in developing larger groups for sustained research experiences. We call to the readership of BAMBED to develop and offer more biochemistry CUREs, to develop careful evaluation of each aspect of CUREs and to study what makes them effective in preparing future biochemists. To assist in each of these areas, we have created a resource to support biochemistry instructors interested in creating and evolving a CURE for their students. This booklet, found as additional material to this publication, exam-

ines in greater depth the evolution of CUREs, the critical elements and assessment of CUREs, and provides key references for continued exploration.

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